Advanced image processing of aerial imagery

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ABSTRACT

Aerial imagery of the Earth is an invaluable tool for the assessment of ground features, especially during times of disaster. Researchers at NASA's Langley Research Center have developed techniques which have proven to be useful for such imagery. Aerial imagery from various sources, including Langley's Boeing 757 Aries aircraft, has been studied extensively. This paper discusses these studies and demonstrates that better-than-observer imagery can be obtained even when visibility is severely compromised. A real-time, multi-spectral experimental system will be described and numerous examples will be shown.

Keywords: Retinex, visual servo, image enhancement, poor visibility, aerial imagery

1. INTRODUCTION

The Visual Information Processing Group at NASA's Langley Research Center has been supporting the Agency's effort to improve pilot visibility in adverse viewing conditions such as night time, fog, haze, and heavy rain. The two primary means of acquiring data have been an Enhanced Vision System (Fig. 1) consisting of a sensor pod mounted under the belly of a Boeing 757 containing three different types of cameras: a long wave infrared (LWIR) in the 7.5-14 μm band, a short wave infrared (SWIR) in the 0.9-1.68 μm band, and an ordinary color video camera. Digital still is acquired from a Nikon D1® professional digital camera. Although the LWIR and SWIR cameras have been the primary systems used for the collection of poor weather data, the visible camera has also been used to collect data, especially during times of low contrast, daylight visibility. In conjunction with the aircraft-mounted video camera system, additional still imagery was collected, especially in turbid imaging conditions. Our focus in this paper will be primarily in using examples from the still imagery from this and other sources to provide examples of enhancements of poor visibility scenes from aircraft.

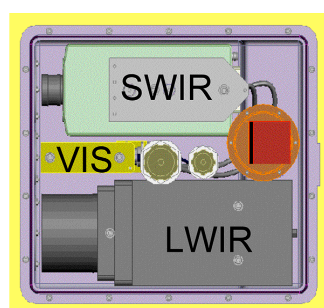

Figure 1. NASA Langley's Enhanced Vision System

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It has long been a problem to match the digital reproduction of a captured image with its human observation[1]. As discussed in a previous paper[1], even under the best recording conditions with the best recording equipment, it is virtually impossible to exactly match the observed scene with the recorded image. Our Group has developed innovative tools (Section 2) that automatically improve the visibility in scenes that have very poor contrast and sharpness.

2. PROCESSING TOOLS

The Group's primary tool for enhancement of aviation imagery has been the Multiscale Retinex (MSR).[5,6] The MSR is a general image enhancement algorithm that provides simultaneous dynamic range compression, color constancy, and sharpness. It was developed for accurate reproduction of imagery, acquired by either analog or digital means, where the scene lighting varies and/or atmospheric conditions hinder good imagery. Additionally, the MSR is capable of providing better-than-observed[8] imagery, especially where scene content is greatly obscured, as in the case of rain, fog, or severe haze. Although the MSR has primarily been applied to conventional multi-spectral and infrared image sources, it is just as effective on non-conventional, computational imagery such as grayscale image representations of traditional medical and airport security imagery[9.10].

More recently, the MSR has been used in support of NASA's Aviation Safety and Security Program under Follow-On Radar, Enhanced Synthetic Vision System Integration Technology Evaluation (FORESITE) flights. The objective in this work has been to develop the capability for helping pilots see in inclement weather by enhancing infrared as well as three-color, visible imagery. This new MSR technology, which incorporates "smart" image enhancement, has far-reaching applications beyond aviation safety, and includes areas such as forensic investigations, medical radiography, and consumer imaging. The original technology has been available for consumer use in a general purpose software package, from TruView Imaging Company, called PhotoFlair® (www.truview.com). It was through various testing of this technology on a wide variety of natural scenes that its utility in the enhancement of aviation imagery was realized.

After testing several thousand images, the Group searched for a way to classify images and make some decisions such as what processing, if any, might be needed. Especially with large catalogs of image data, not all of the images need to be enhanced. This led to the development of the Visual Measures (VM) and corresponding Visual Servo (VS) (Figure 2).[15] The VS classifies an image as "good" or "poor" based on its contrast, brightness, and sharpness scores. Corresponding decision criteria are used to either enhance the image using an iterative process or simply pass it through to the output device. Although any contrast enhancement process can be used with the VS, the Group has been working primarily with the MSR because of its proven success for a wide variety of scenes, over a variety of input sources. The VS uses a two-pass, contrast, brightness, and sharpness enhancement phase along with a parametric histogram modification which is triggered in the case of hazy scenes. The VS adds an active visual quality measurement and feedback control element to the previously passive retinex processing, which extends performance from wide dynamic range imaging to encompass all imaging including the very narrow dynamic range imaging associated with poor visibility conditions (fog, haze, rain, snow, dust, dim light).

One of the metrics of the VS, the Visual Contrast Measure (VCM), has been computed for hundreds of FORESITE images, and for major classes of imaging – terrestrial (consumer), orbital earth observations, orbital Mars surface imaging, and underwater imaging, the results of which are presented in a companion paper entitled, *Comparison of Visual Statistics for the Image Enhancement of FORESITE Aerial Images with Those of Major Image Classes*. The metric quantifies both the degree of visual impairment of the original, un-enhanced images as well as the degree of visibility improvement achieved by the enhancement process.

The VCM is an internal primary metric of the VS enhancement "smart" controls and quantifies what portion of an image frame has good contrast.

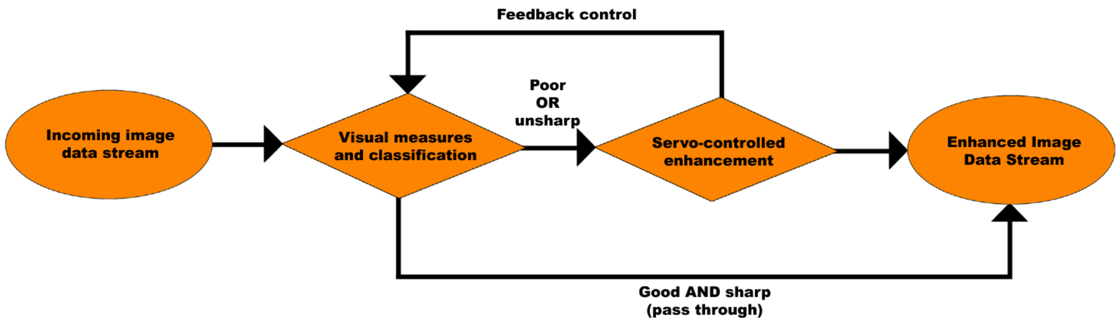

Figure 2. Schematic of VS

3. COMPARISONS

In practice, the VS with MSR performs extremely well over a wide variety of scenes. Comparisons with other automatic image processing methods have been made, all of which show a very high rate of success for the MSR/VS method.[10,12] Comparisons have been made with Adobe Photoshop® histogram equalization and auto levels, Intrigue Technologies Shadow Illuminator®, Applied Science Fiction Digital SHO®, Extensis Intellihance®, Microsoft Picture It!®, Polaroid Before and After®, and Computerinsel GmbH Photo Line®. Although all of these products perform well on certain scenes, the MSR, especially with the VS, demonstrates superiority over all of these other methods in a far greater number of cases, especially those associated with poor visibility scenes.

4. APPLICATIONS TO AERIAL IMAGERY

During August and early September, 2005, the research Boeing 757 of NASA Langley Research Center (Figure 3) was used to conduct a series of test flights collectively called the FORESITE program. These test flights were designed to test and demonstrate a number of new aviation safety technologies. Langley's highly modified Boeing 757 conducted low altitude (2000 feet) flights around NASA's Wallops Flight Facility, making numerous low approaches at 200 feet for visualization of the runway during landing approach. We participated in the test flights with one goal being to acquire a high volume of very poor visibility aerial imagery and test the use of our VS and MSR methods. The FORESITE experiments were conducted during the height of late summer stagnant air conditions. As a result, visibility along the flight paths from Newport News-Williamsburg Airport, VA to Wallops Flight Facility, VA and back was seriously impaired by conditions which ranged from severe haze to combinations of severe haze interspersed with patchy clouds. Ground terrain was only very faintly visible and on several flights there was no visibility of the ground terrain. Therefore we were able to acquire considerable image data at or exceeding the extremes of visibility. Imagery was collected on eight flights, with 200 to 400 digital color, still image frames per flight. The images were acquired with a Nikon D1® camera and were shot through the side window of the aircraft.

5. DISCUSSION OF FORESITE IMAGERY

Figure 3. NASA Langley Boeing 757 Aries aircraft

In the following examples, pairs of images are presented, demonstrating the utility of the MSR/VS enhancements to produce better-than-observer visibility. All of these images were acquired during the FORESITE flight tests with a Nikon D1® camera system. Imagery from the IR cameras, see Hines et.al. *Real-time Enhancement, Registration, and Fusion for aMulti-Sensor Enhanced Vision* which also addresses the hardware issues for the real-time enhancement, registration, and fusion of the image sources for the multi-sensor system.

The D1® images were acquired at a spatial resolution of 2000 x 1312 pixels and a spectral resolution of 8-bits per color. They were saved in the highest quality JPEG setting, giving about 6:1 compression. Compression was used to allow short duration between shots where needed, and to duplicate many other commercially available camera systems. We primarily used the Nikkor AF 50mm f1.8 and the Nikkor AF 80-200mm f2.8 lenses.

In Figure 4, an example of low image turbidity is shown. Loss of scene contrast is primarily due to poor clarity in the window of the aircraft. Although there is very little apparent scene degradation, the enhancement provides clarity of detail evidenced by increased contrast and sharpness. Colors are more vivid and fine details are delineated. There is more detail in the grassy areas for example as well as in the dark areas surrounding the guard gate near the top left of the image. This scene epitomizes friendly flying conditions where "Visual Flight Rules" (VFR) apply.

Figure 4. Mild scene turbidity due to haze.

Figure 5 shows an example of moderate scene turbidity due to summer haze and the corresponding enhancement. Overall, the image is much sharper and brighter. Detail in ground features is much better. Individual cars can be seen as well as detail on the distant land at the top of the image, none of which can be seen in the original image. Again, VFR apply, but the haze is now degrading visibility considerably. Application of the MSR/VS improves visibility by about two-fold giving the pilot more time to adjust to objects on the runway during a landing approach.

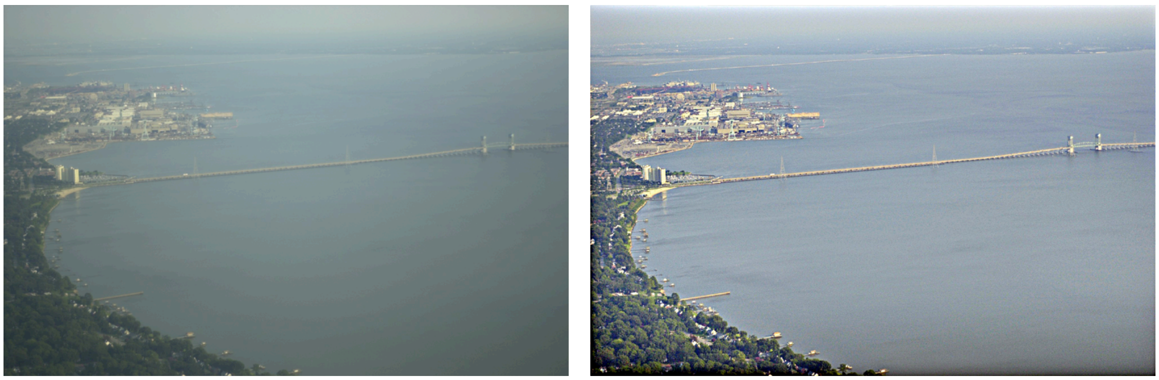

Figure 5. Moderate scene turbidity due to haze.

In figure 6, visibility of ground features was diminished to zero due to very heavy haze. Absolutely nothing was visible with the unaided eye. In the enhancement, not only does the bridge show up but both spans are visible as well as the bridge supports and a truck. Even waves can be seen along the shore in the background. A pilot under VFR, looking for a suitable location for an emergency landing, would need to differentiate between water and land or the presence of obstacles.

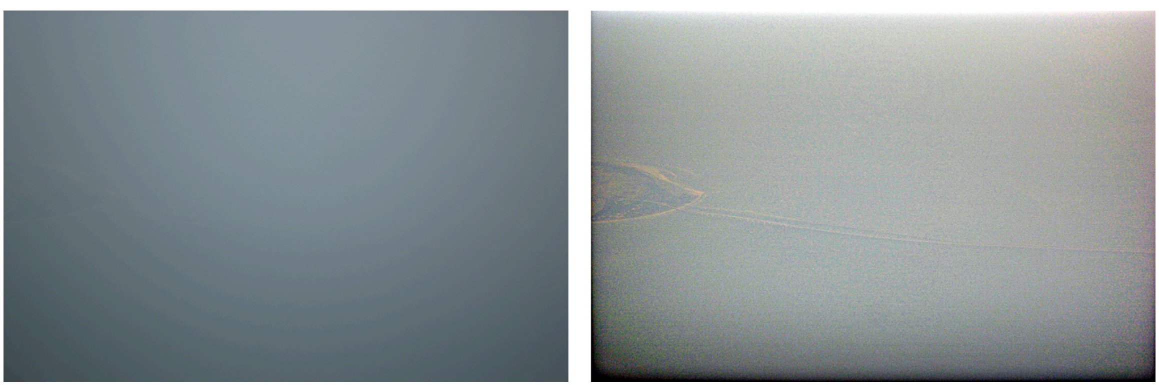

Figure 6. Severe scene turbidity due to haze. Beyond visibility limits.

The example in figure 7 shows a combination of thin clouds and heavy haze which reduced the visibility of ground features to near zero. The high contrast between light roads and dark fields is barely visible while in the enhancement, rich detail can be seen such as plowed rows in the fields and a farm house. A pilot could more easily pick out a hard road versus a rough field of vegetation for an emergency landing.

 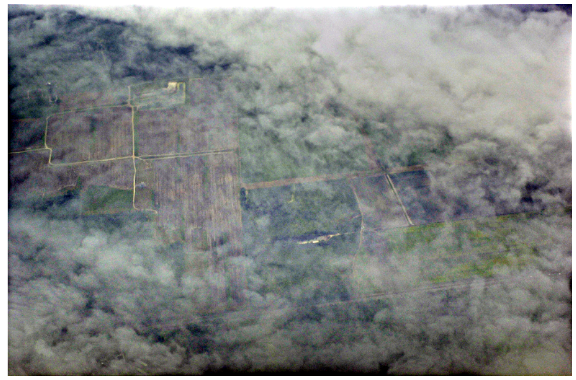

Figure 7. Severe scene turbidity due to cloud cover. Beyond visibility limits.

This next example, in figure 8, demonstrates the utility of the processed image for detecting objects. During direct observation, the contrast between the shoreline and the water was fairly easily observed. The aircraft below however was almost completely hidden by the clouds above it and was not seen until it was almost out of the cloud. Note that color on the aircraft can easily be seen in the enhancement but none at all can be determined in the original image.

 

Figure 8. Object detection in turbid scene.

Especially in cases of pilot visibility, object recognition is much easier with enhanced imagery. Figure 9 illustrates this clearly. In the original image, the heavy haze has obscured the image such that the most prominent feature is visible but not identifiable. What could easily be mis-identified as a highway in the original image turns out to be a power line easement among trees in the enhancement. Although some features in the original image were visible, identification was near impossible without the enhancement.

 

Figure 9. Object recognition in turbid scene. At visibility limits.

6. DISCUSSION OF NOAA IMAGERY

Figure 10. NOAA Cessna Citation (in foreground)

During the 2005 hurricane season, the United States suffered enormous losses in life and property from several hurricanes, namely hurricanes Dennis, Katrina, Ophelia, Rita, and Wilma. To help with the emergency response following these devastating storms, the National Oceanic and Atmospheric Administration (NOAA) conducted aerial survey missions of the areas of destruction. Using two cameras aboard a highly modified Cessna Citation, (Figure 10) these areas were photographed from an altitude of 7,500 feet and many of the images were placed on a publicly-accessible website[14]. In addition to disaster response, NOAA collects imagery in support of coastal mapping and for updating shore features on their nautical charts.

Hurricane Katrina made landfall along the Florida coast before crossing the gulf to hit the Louisiana and Mississippi coasts at the end of August. In the example in Figure 11, a cloud is shadowing part of the scene further obscuring an already hazy and low contrast image. The enhancement however brings out much detail in the shadowed area while not "overexposing" the directly illuminated areas. The enhanced image shows many vehicles clearly which were not readily visible in the original image. Tarps can be seen covering damaged roofs while debris can be seen scatter about the ground, neither of which are obvious in the original image. Better visibility from the air could me more accurate damage assessments and especially more efficient search and rescue operations.

Figure 11. Aftermath of hurricane Katrina

At the end of September of 2004, hurricane Jeanne struck Southern Florida and traveled up the state and then Northward through the Carolinas and Virginia, causing much flooding from heavy rains. In the example in Figure 12, the scene shows little damage to a relative simple scene but once enhanced, the damage is apparent. Downed trees, especially near the right of the image are obvious. Although debris along the beach is visible in the original image, it is much clearer in the enhancement and sediment outwash and sand barring is evident that was not seen in the original image. Again, better assessment of damage can be made and in this case, for the navigability of waterways.

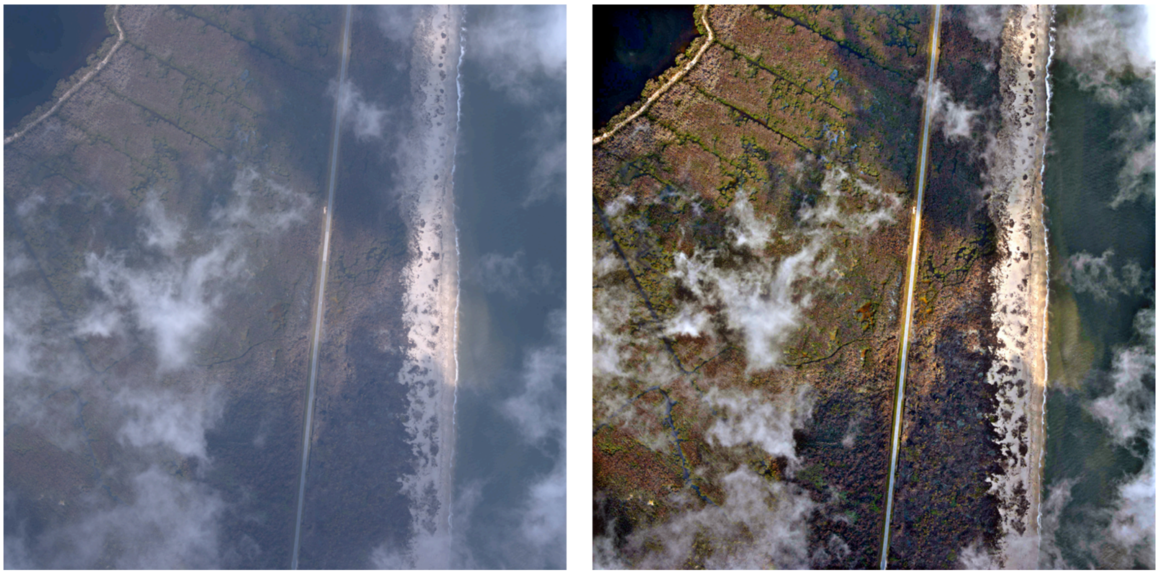

Figure 12. Aftermath of hurricane Jeanne

During the second and third week of September, hurricane Ophelia caused widespread damage along the South Carolina and North Carolina coasts. In Figure 13, a shallow water area is shown before and after enhancement. The enhanced image very clearly shows features including sand bars and coast lines. Comparison with images taken before the storm would be made much more easily with the enhancement than the low contrast and unsharp original image.

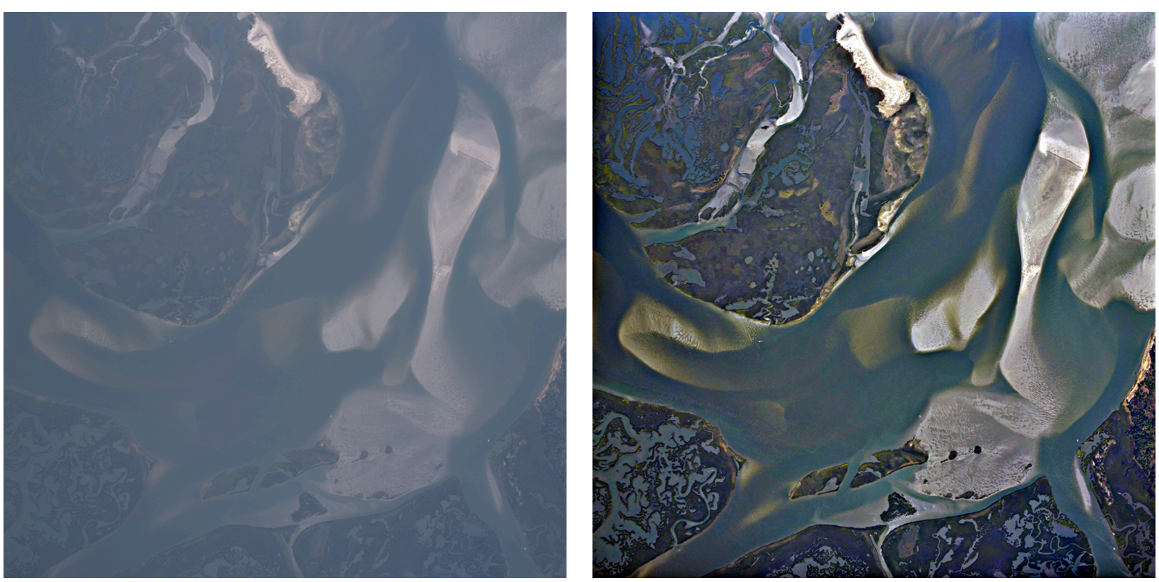

Figure 13. Aftermath of hurricane Ophelia

Hurricane Wilma crossed the Southern Florida peninsula during the third week of October. The example below in Figure 14 shows a coastal area affected by the storm. Although some sediment wash can be seen in the original image, its full impact cannot be seen without enhancement. Other impacted areas are revealed through enhancement including both lakes near the bottom of the scene.

Figure 14. Aftermath of hurricane Wilma

7. CONCLUSIONS

The effectiveness of Langley's Multi-scale Retinex combined with the Visual Servo has proven its superiority over other automatic methods of image enhancement. Its dramatic performance with its strong increase in local contrast and overall sharpness, especially in scenes of poor visibility, make it a prime candidate for usage in aerial imagery. Its usefulness extends beyond the range of human observation, bringing out detail that cannot be seen with the unaided eye such as in cases of heavy haze and thin clouds. Its application to terrestrial imagery has shown usefulness in scenes of heavy rain and fog suggesting similar results in aerial imagery in these conditions as well. This paper summarized extensive demonstrations of enhanced visibility in aerial imagery of several types. The value of this enhancement technology is very well illustrated when one considers that search and rescue operations as well as property damage assessments can be much more easily carried out by the use of better imagery.

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